No-till Seeded Winter Wheat: Influence of Genotype on Water Use, Crop Growth and Yield in Contrasting Environments

D.R. Domitruk and D.B. Fowler
Crop Development Centre
University of Saskatchewan
Saskatoon, Saskatchewan

ABSTRACT

Genotypic variation for yield among a population of winter wheat lines grown under a range of natural drought stress conditions was examined in two independent experiments. Extensive variation in yield among twenty-eight advanced winter wheat lines grown under low moisture stress conditions was observed. When the same lines were grown under moderate to severe moisture stress the level of variability decreased.

Variation in yield among ten advanced winter wheat lines grown under varying intensities of late season drought stress was also assessed. Lines with the highest yield had the greatest water use efficiency for grain yield. There were no genotypic differences in water use or water use efficiency for above ground dry matter production and there were no genotype x environment interactions for any measured trait.

In a third experiment the yield potential of Norstar winter wheat in each of the major soil zones in Saskatchewan was established. The highest yield potential for Norstar winter wheat occurred in the black/grey soil zone, particularly in the Yorkton/Kamsack corridor. The brown soil zone had the lowest yield potential while the dark brown soil zone had intermediate yield potential.

INTRODUCTION

Stubbled-in winter wheat typically displays a higher average maximum yield compared to spring wheat under rainfed conditions in Saskatchewan (Entz and Fowler, 1991). Actual average maximum yield for most crops varies across the major soil zones of the province. It is generally accepted that the incidence and intensity of moisture stress plays a major role in defining average maximum yield.

Regional differences in average maximum yield represent differential expressions of genetic yield potential. Plant breeders are concerned with yield potential under sub-optimal conditions as a characteristic of both genotype and surrounding environment. Therefore, in breeding for tolerance to stress it is advantageous to employ a system of multilocational testing in order to analyze genotypic performance in natural stress environments. This type of screening identifies differential genotypic performance across environments.

Drought stress always exists to some degree in the semi-arid zones in Saskatchewan. One reason for this is that much of the plant available water in the root zone is depleted by the crop during its early development. Further development and yield come to depend on growing season precipitation. This root zone moisture depletion is particularly evident in stubbled-in winter wheat which, as a re-crop, may begin development on limited stored soil water.

Wheat plants display differential sensitivity to moisture and heat stress. Sensitivity depends on plant growth stage and pre-stress conditioning (Doorenbos and Kassam, 1979, Singh, 1981). Winter wheat yield has been shown to be dependant on the rate of evaporation during the two week period prior to anthesis (Entz and Fowler, 1988). This dependency is a reflection of the large impact of stress on winter wheat yield during the period just prior to anthesis. Therefore, knowledge of the timing of stress events is critical when either genotypic or locational factors are assessed for their effect on yield. However, annual variation in weather make the timing and intensity of stress events unpredictable. This unpredictability presents a challenge to plant breeders who wish to quantify the effect of location on the yield potential of new genotypes.

Drought stress influences numerous functions simultaneously and it is difficult to ascertain which trait is best associated with drought tolerance. This difficulty is further magnified by the fact that stress varies in timing and intensity and traits determining stress tolerance may change accordingly. Water use efficiency for grain yield is a physiological trait that is often used to assess performance under stress. Expressed as grain production per unit water used this trait is derived from growth models for water-limited crops (Passioura, 1983).

In the present studies, the yield potential of several advanced lines and recommended cultivars of winter wheat were examined across several environments to determine the effect of natural drought stress on water use efficiency and grain yield.

MATERIALS AND METHODS

1. Regional variety adaptation trials

In the first series of experiments, twenty-eight advanced lines of winter wheat and two registered cultivars (Norstar and Norwin) were tested for yield from 1987-1990. A significant characteristic of the advanced lines is that they possess a level of winter hardiness similar to Norstar. Trials in Saskatchewan were located at Shaunavon, Elrose, Saskatoon, Clair, Canora, Porcupine Plain, Melfort and Indian Head. Some of the lines were also tested in trials in Manitoba at Portage la Prairie and Winnipeg. Trials were no-till seeded into standing stubble of either canola, barley, or flax. Between 36-40 kg ha^{-1} P_2O_5 was placed with the seed. Between 136-200 kg ha^{-1} N (34-0-0) was broadcast in early spring. Three replicates of each genotype were included. The data from these trials was subject to an analysis of variance. A mixed model was employed in which genotypes were considered as a fixed variable and locations and years as random variables.

2. Regional differences in grain yield potential

In the second series of experiments, the cultivar Norstar was evaluated for yield in seventyseven small plot trials from 1982-1990. Trials were carried out in each of the four major soils zones in Saskatchewan. Seeding and fertilizer practices were similar to those described above.

3. Genotypic and environmental variation for yield and associated traits

In the third series of experiments, seven advanced lines and two registered cultivars (Norstar and Norwin) of winter wheat were examined. A cultivar from the Soviet Union , Alabaskaja, was also included making a total of ten genotypes. These experiments were carried out during the 1989-90 and 1990-91 seasons at four locations in Saskatchewan: Shaunavon, Elrose, Clair and Canora. Trials were no-till seeded into canola or wheat stubble. Fertilizer practises were as indicated above. Three replicates of each genotype were included.

Soil water to 110 cm was measured over the period from mid-May to harvest using a neutron probe (Troxler Laboratories). Surface soil moisture (0-10 cm) was determined gravimetrically. Soil water measurements were taken at the beginning and end of four growth periods; tillering, stem extension, booting/anthesis and grain filling. These periods correspond to Zadoks' growth stages 25-31, 31-45, 45-60 and 60-85 respectively. The amount of plant extractable water in each profile was determined by taking the difference between the highest and lowest measured volumetric water content (Ritchie, 1983). Plots were sampled for dry matter accumulation at the same intervals. Rainfall was recorded at each location with a tipping bucket rain gauge equipped with a data logger. Class 'A' pan evaporation was measured by Environment Canada weather stations near each site.

Variables considered in the were water use during each growth phase (ET1-ET4) and total water use over the season (GSET). Water use efficiency for dry matter during the pre-anthesis period (WUEPA), water use efficiency for grain yield (WUEGY) and grain yield at harvest were also included in the analysis. Analysis of variance with genotypes considered as a fixed variable was employed to determine genotype, location and genotype x location effects.

RESULTS AND DISCUSSION

1. Regional variety adaptation

Variation in yield potential existed among winter wheat lines grown under drought stress (Fig. 1). A significant trial by winter wheat line interaction ($P<0.05$) existed for yield of lines evaluated in these experiments. This interaction indicates that the winter wheat lines exhibited a differential response to varying levels of drought stress. However, the practical importance of the interactions were minor. A comparatively larger amount of variation in yield potential was revealed when data from trials carried out under high moisture conditions were included in the analysis (Fig. 2). A large trial by winter line interaction existed in this case. Yield of the lines examined in these experiments show greater variability under high moisture conditions compared to conditions of moisture stress.

2. Regional differences in grain yield potential.

Regional differences in grain yield potential existed for Norstar winter wheat (Fig.3). Highest yield potential was in the black/grey soil zone, particularly in the Yorkton/Kamsack region. The dark brown soil zone recorded the second highest yield potential with the lowest average yield occurring in the brown soil zone.

Given the association between evaporative demand (Robertson, 1984), available soil water at anthesis (Entz and Fowler, 1988) and yield of winter wheat, it is likely that the differences in yield potential across soil zones were related to differences in crop water environment. Hence, the average yield obtained over several years in a given soil zone may be governed by the average crop water conditions in that soil zone. Within a soil zone the crop water situation varies greatly from year to year due to variation in rainfall distribution, temperature and evaporation. Since the occurrence of drought stress is common in all zones, the timing and intensity of stress in a given year dictates the yield potential for a given location.

3. Genotypic and environmental variation for yield and associated traits.

The ten genotypes considered in this study had similar water use patterns within growth periods and over the entire season (Table 1). Similar results were found for WUED or WUEPA. A significant genotypic effect was present for grain yield and WUEGY. Lines that exhibited the highest grain yield also possessed the highest WUEGY. No genotype x environment interaction was detected for any trait measured including grain yield and WUEGY.

Yield stability is considered a desirable trait (Smith, 1982). High yielding genotypes tend to be associated with a lack of stability. Therefore, selecting genotypes based on stability often reduces yield potential under favourable conditions (Rossielle and Hamblin, 1980). However, although there were differences in yield potential among the genotypes evaluated in the present study they did not respond differentially to changes in environment.

A possible explanation for the apparent yield stability among the ten genotypes considered in this trial is that the drought stress encountered at Shaunavon, Clair and particularly at Elrose occurred late in the growth of the crop. Most trials had very good initial growth but tended to deplete water stored in the profile prior to anthesis (Fig. 4). This depletion of water reserves occurred as evaporation rates reached a peak and rainfall became limited. It is likely that any expression of differential yield potential was masked by the overriding influence of stress during anthesis and grain formation. A great degree of floret abortion was recorded for all genotypes at Elrose in 1989. The above scenario did not exist at Canora. Another possible explanation for the apparent stability of genotype rankings is that the range of yield potentials encountered in this study was rather narrow. Although there was a genotypic effect for grain yield, the average yield in each case was between 2100-2600 kg ha^{-1}. In comparison, Norstar yielded an average of 3500 kg ha^{-1} in the Yorkton/Kamsack (Canora) area and 1500 kg ha^{-1} in the brown soil zone over 8 seasons (Fig.3). The yield potential exhibited in the present study was midway between the two established extremes. Thus, the prevailing environments in the present trials did not allow for full expression of the yield potential of most of the lines. Conversely, the level of drought experienced in the present trials was not adequate or general enough to inflict yield reductions in the cultivar Norwin which typically performs poorly under early season stress conditions. Had this early season stress occurred the potential for genotype x environment interactions may have been greater.

SUMMARY AND CONCLUSIONS

The average yield potential for winter wheat in each of the major soil zones in Saskatchewan has been quantified. The highest yield potential exists in the black/grey soil zone while the lowest yield potential exits in the brown soil zone. The Yorkton/Kamsack region of the black soil zone displayed exceptional yield potential. The differences in yield potential for winter wheat across the soil zones is likely due to different average levels of evaporation during the pre-anthesis period along with differing average levels of available water in the root zone during the same period (Entz and Fowler, 1988).

The level of genotypic variation among thirty winter wheat lines was greater under low compared to moderate to severe intensities of drought stress. Some lines exhibited drastic changes in yield potential over environments differing in rainfall and evaporative demand. Therefore, it is likely that important genotype x environment interactions for yield exist.

Genotypic variation for yield among a population of winter wheat lines under varying intensities of late season drought stress was confirmed. The highest yielding lines possessed the highest water use efficiency for grain yield. The lines did not differ in the amount of water they transpired over the season. Therefore, the higher yielding lines simply displayed a more efficient conversion of water into grain yield. It is speculated that this trait may be valuable in maintaining yield under drought stress.

Table 1. Mean water use and water use efficiency of ten selected genotypes grown at four locations in Saskatchewan in 1989-1990.

Line	Yield kg ha^{-1}	WUEGY kg ha^{-1} mm^{-1}	GSET mm	ET1 mm	ET2 mm	ET3 mm	ET4 mm	WUEPA kg ha^{-1} mm^{-1}	WUED kg ha^{-1} mm^{-1}
808	2586a	11.98ab	216.4	47.5	33.9	47.8	82.6	28.7	32.7
375	2573ab	12.72a	212.2	44.5	31.3	46.2	85.7	26.3	32.1
30	2475abc	12.15ab	209.6	46.3	32.7	43.5	83.5	31.0	33.1
997	2473abc	11.78bcd	211.6	45.0	32.9	47.7	84.7	30.5	32.3
995	2436abc	11.89abc	205.8	45.6	33.1	43.8	77.2	27.7	30.5
736	2427abc	11.54bcd	210.9	49.5	33.4	46.0	77.7	28.9	30.8
52	2403bc	11.38bcd	212.2	48.3	34.5	42.7	77.7	31.9	31.9
48	2328c	11.11cd	214.1	46.5	32.6	44.7	86.9	28.8	30.0
784	2312cd	10.94de	209.1	52.2	33.2	42.6	79.9	28.6	29.8
996	2155d	10.23e	209.5	48.7	31.8	41.5	85.2	27.5	29.2

Means followed by the same letter are not significantly different at the 0.05 probability level.

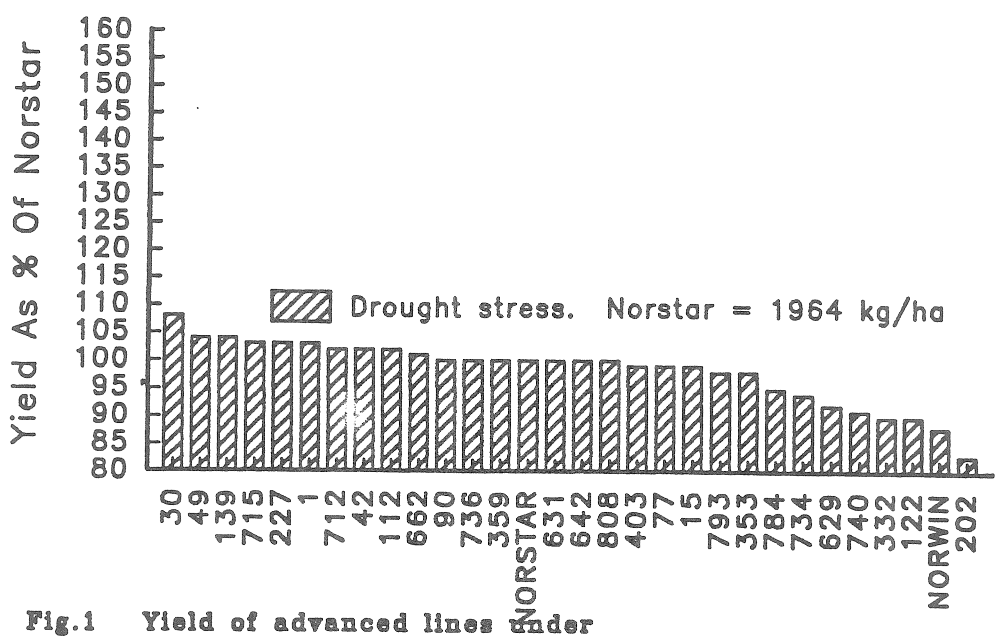

Fig.1 Yield of advanced lines under drought stress. Mean over 4 years and 10 locations.

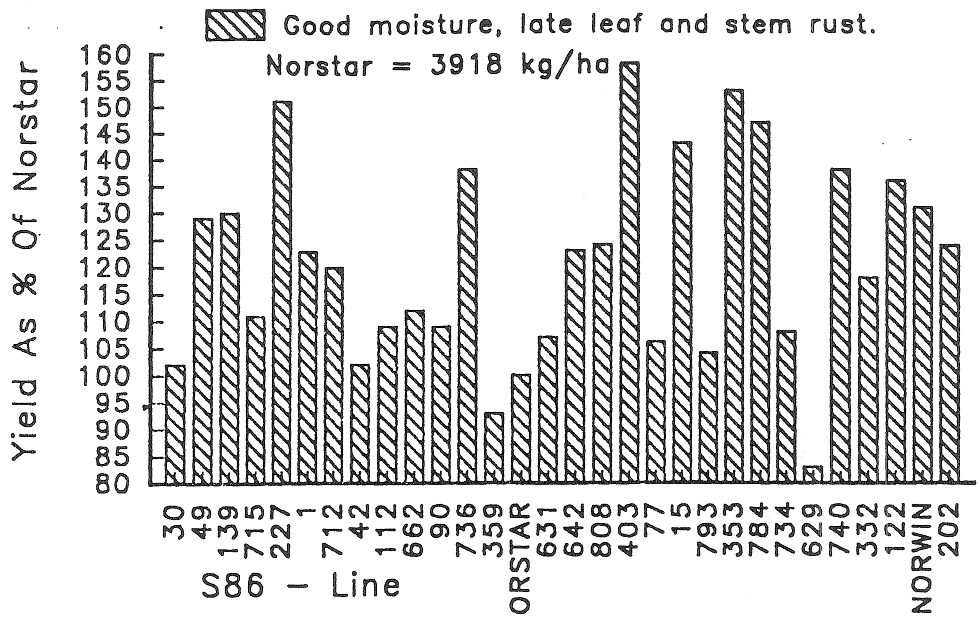

Fig.2 Yield of advanced lines
Mean over 4 years and 10 locations.

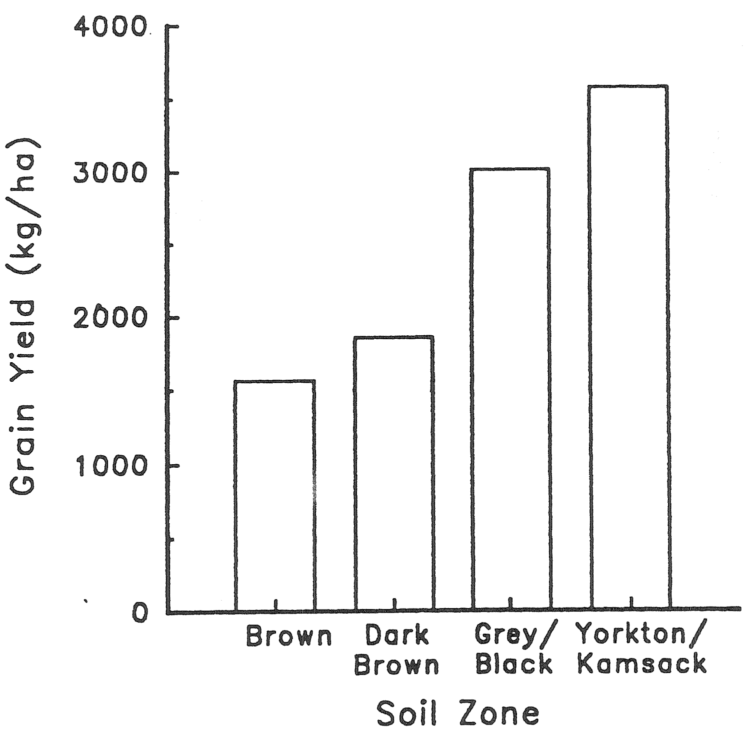

Fig. 3. Mean yield potential over 77 trials 1982-1990.

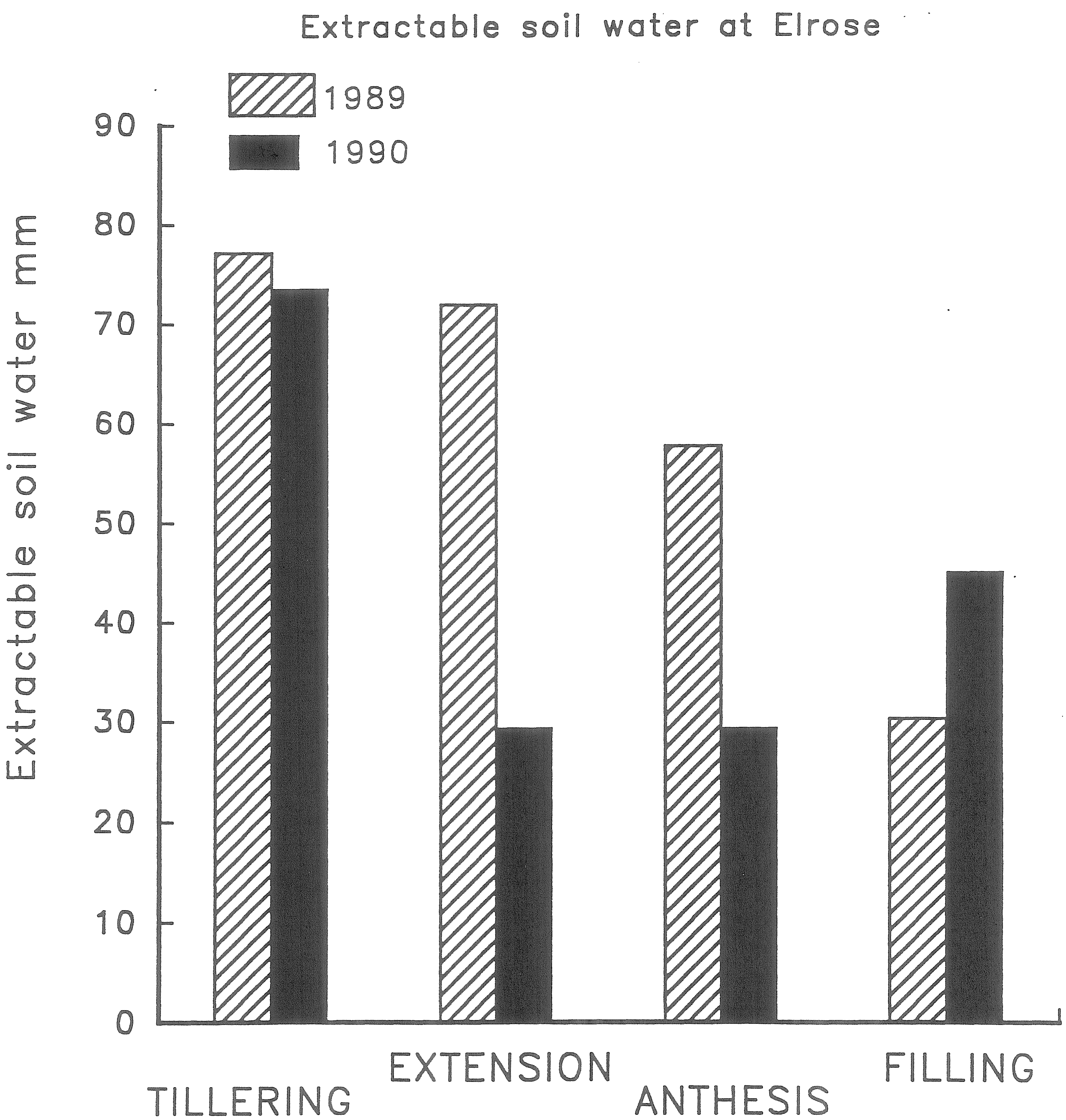

Fig. 4.Extractable soil water at Elrose for 1989 and 1990.

REFERENCES

Doorenbos, J. and A.H. Kassam. 1979. Yield response to water. FAO publications no. 33. pp. 164-170.

Entz, M.H. and D.B. Fowler. 1988. Critical stress periods affecting productivity of no-till winter wheat in western Canada. Agron. J. 80: 987-992.

Entz, M.H. and D.B. Fowler. 1991. Agronomic performance of winter compared with spring wheat produced in western Canada. Agron. J. 83 (accepted for publication).

Passioura, J.B. 1983. Roots and drought resistance. Agric. Water Management 7: 265-280.

Robertson, G.W. 1974. Wheat yields for 50 years at Swift Current, Saskatchewan in relation to weather. Can. J. Plant Sci. 54: 625-650.

Rosielle, A.A. and J. Hamblin. Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci. 21: 943-946.

Singh, S.D. 1981. Moisture-sensitive growth stages of dwarf wheat and optimal sequencing of evapotranspiration deficits. Agron. J. 73: 387-391.

Smith, E.L. 1982. Heat and drought tolerant wheats of the future. Proceedings of the national wheat research conference, 1982. USA-ARS, Beltsville, Maryland. pp.141-147.